Implementation and Calibration of the LS-DYNA PID Controller for Female Cervical Muscles

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1. Background

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Whiplash Associated Disorders (WADs) or Whiplash Injuries are **a worldwide concern** [1,2,3]

1. Kullgren, A. et al., (2007);
2. Chen, H.B. et al., (2009);
3. Bannister, G. et al., (2009).

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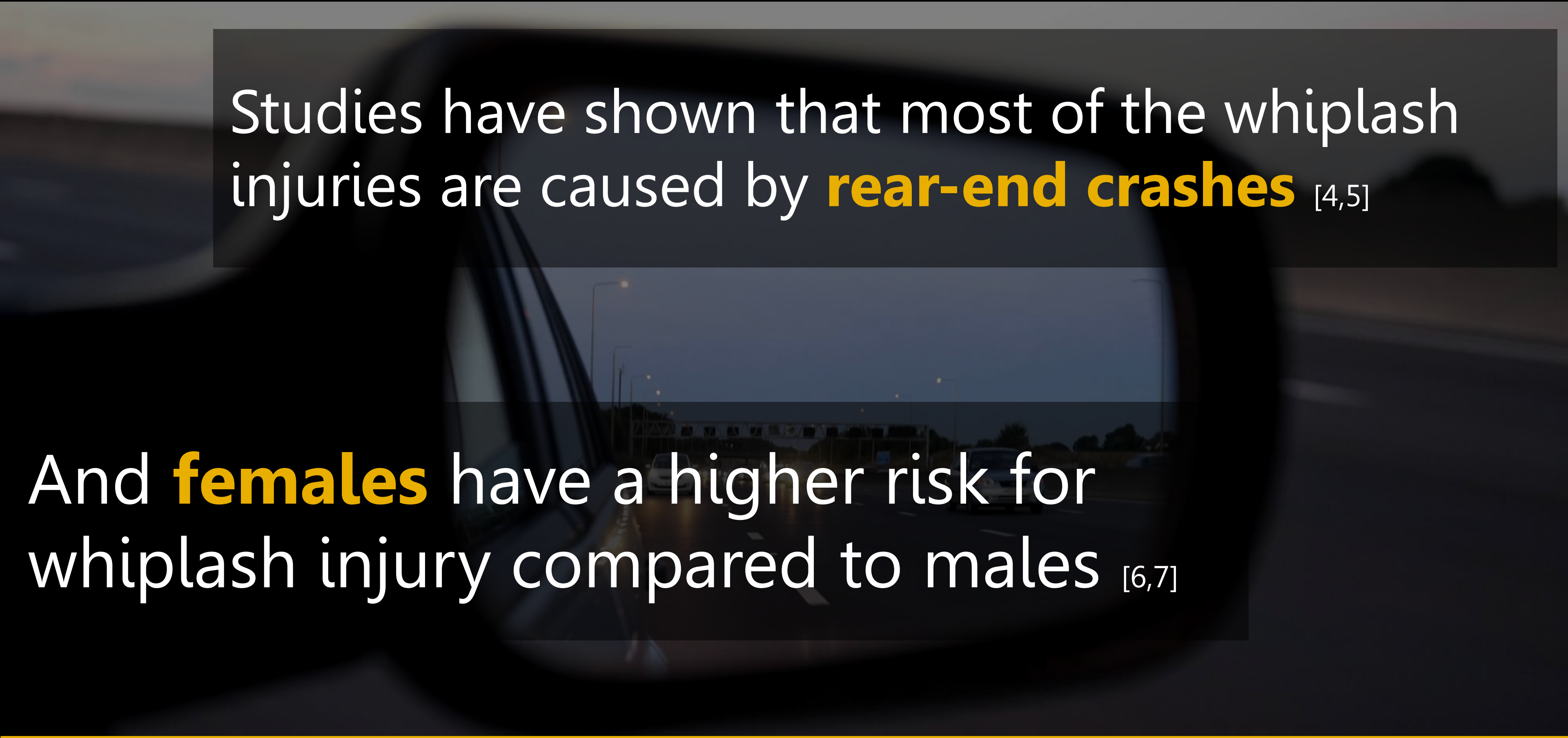
1. Background

300.000 of European Union citizens suffer from whiplash injuries [1]

Incidence of whiplash injuries is estimated **3.8 per thousand population** [2]

In Australia, the whiplash injuries rate is estimated **106 per 100.000 population** [3]

1. Kullgren, A. et al., (2007);
2. Chen, H.B. et al., (2009);
3. Motor Accident Insurance Commission., (2015);

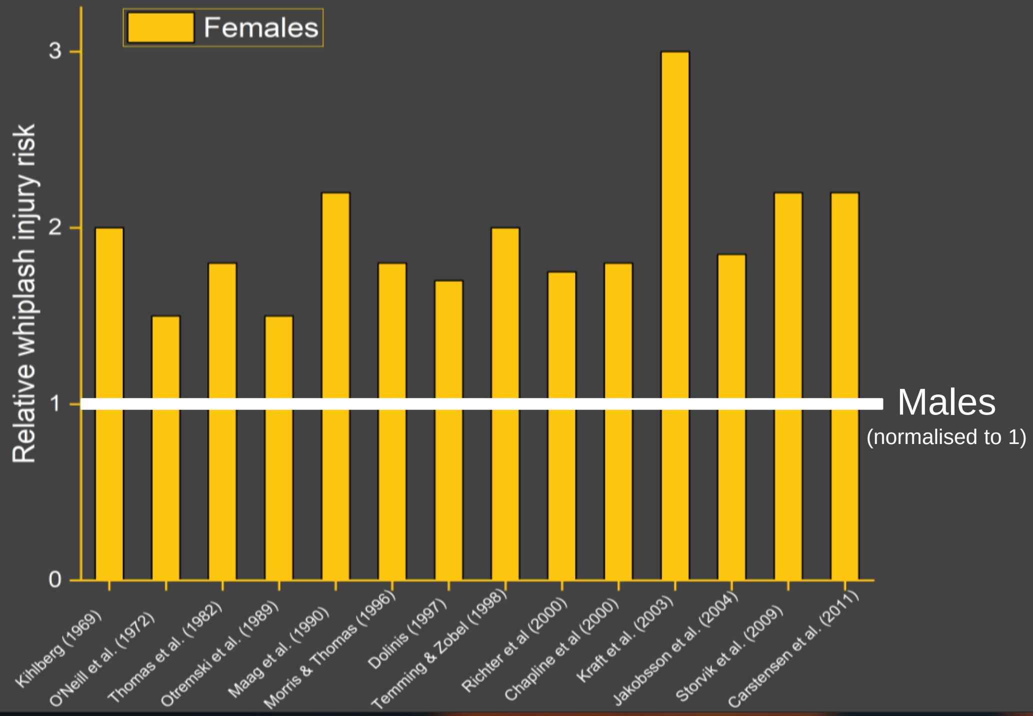


Studies have shown that most of the whiplash injuries are caused by **rear-end crashes** [4,5]

And **females** have a higher risk for whiplash injury compared to males [6,7]

4. Galasko, C.S.B. et al., (1993);
5. Krafft, M., (1998);
6. Dollnis, J., (1997);
7. Jonsson, B., (2008)

In fact, up to **3 times higher** than males... [8]

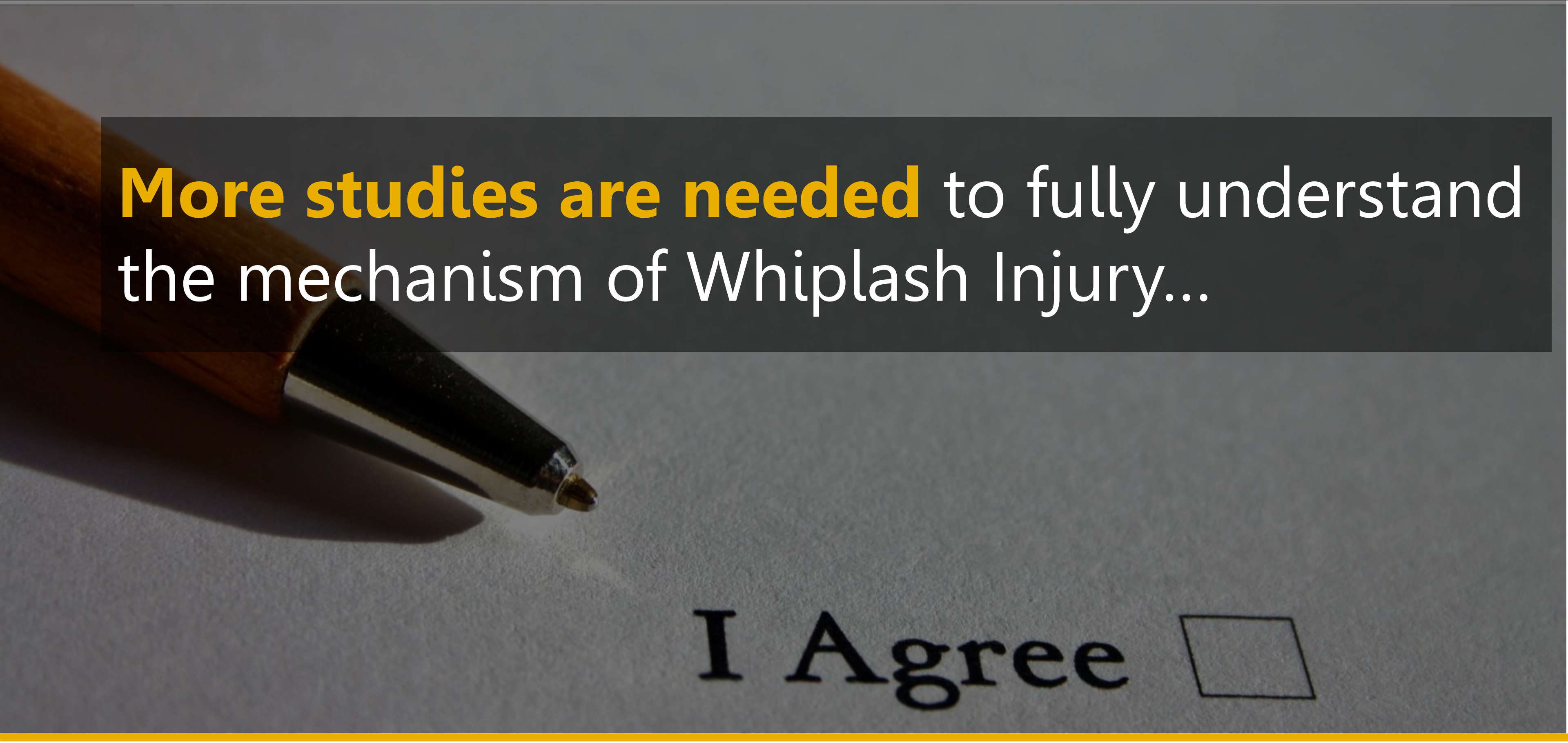


8. Summarised by Carlsson et al., (2011)

Despite the high number of WAD victims especially females,

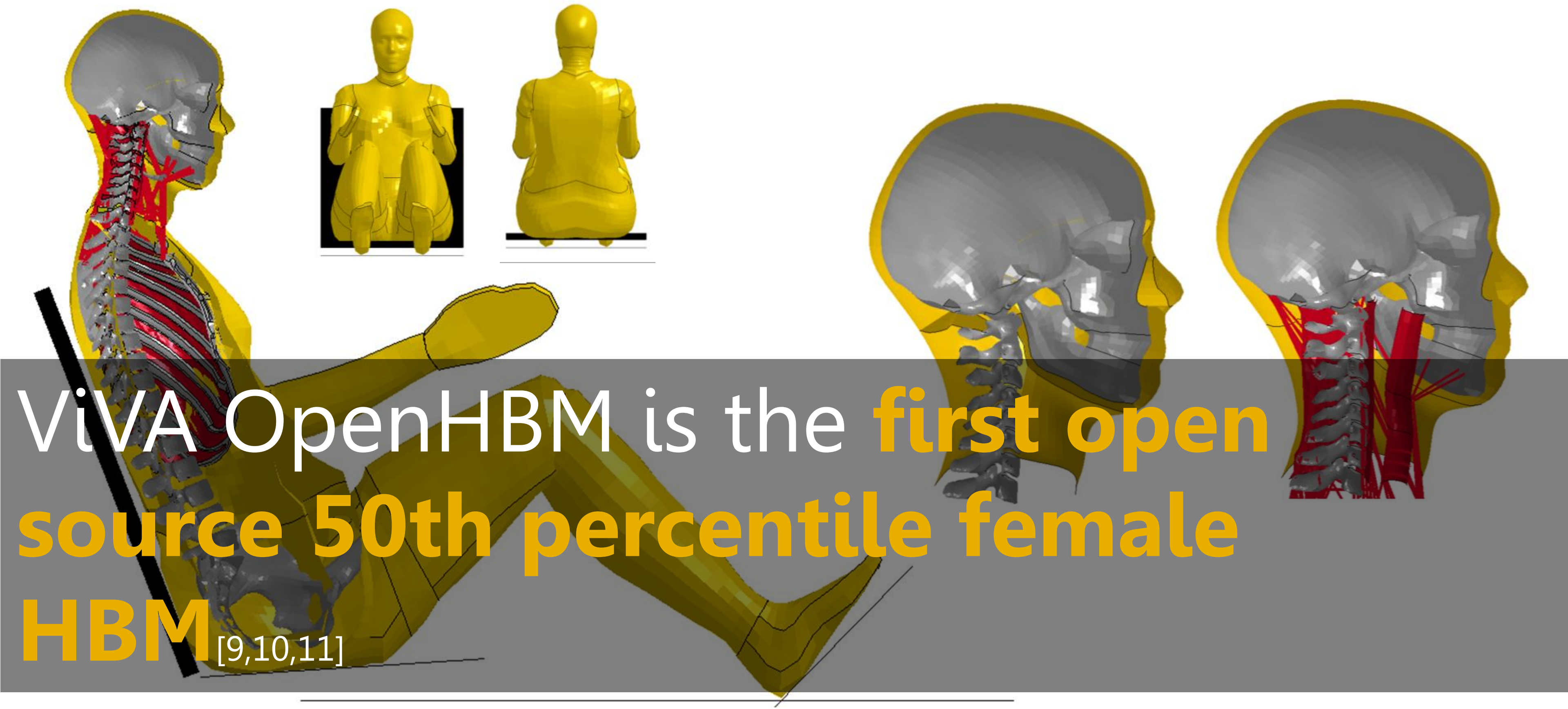
the injury mechanism of WADs is **unclear and not fully understood**.

More studies are needed to fully understand the mechanism of Whiplash Injury...



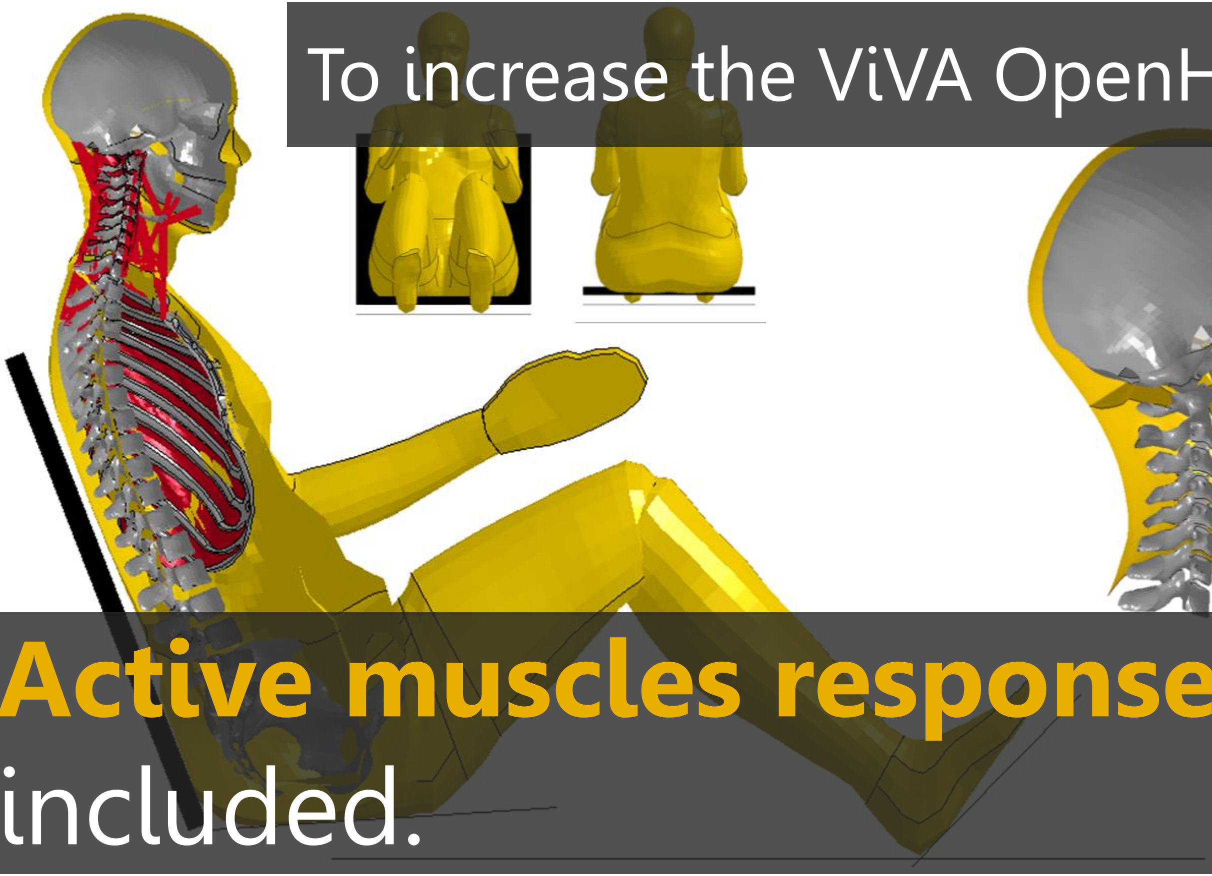
HBMs are **powerful tools** for traffic safety research.

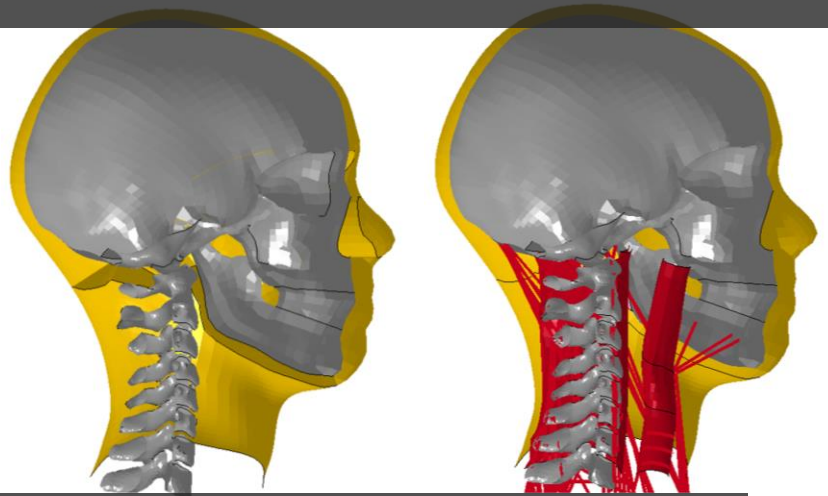
Until recently a HBM that represents the 50th percentile female **did not exist...**



ViVA OpenHBM is the **first open source 50th percentile female HBM**[9,10,11]

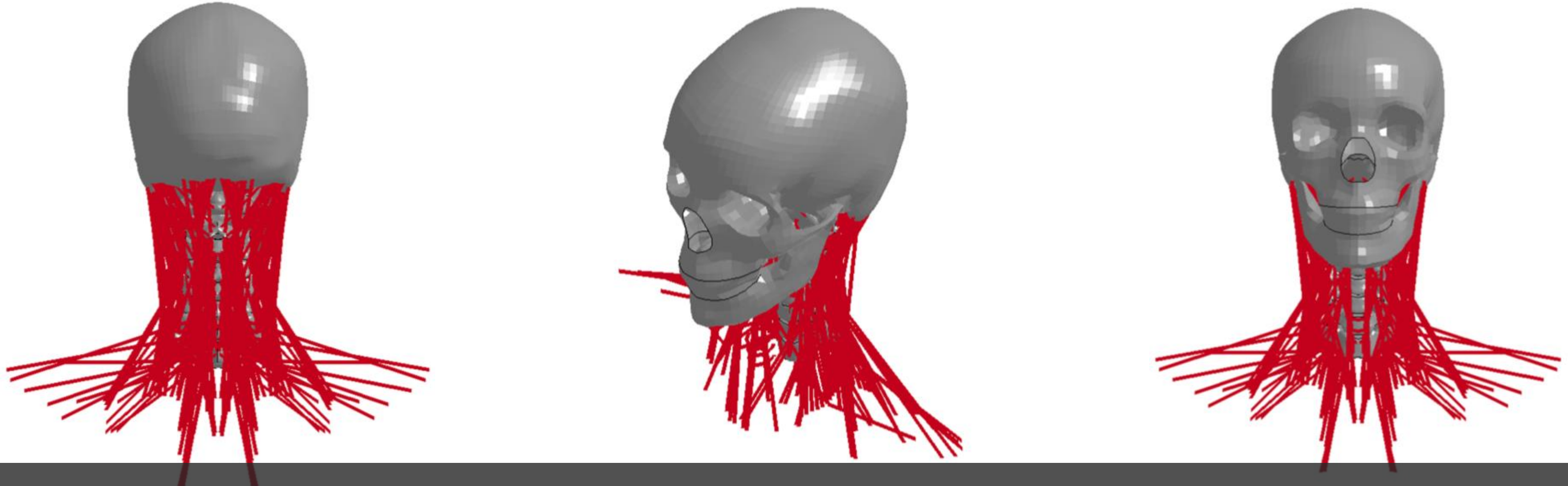
9. Östh et al., (2016)
10. Östh et al., (2017)
11. Östh et al., (2017)





To increase the ViVA OpenHBM's biofidelity,

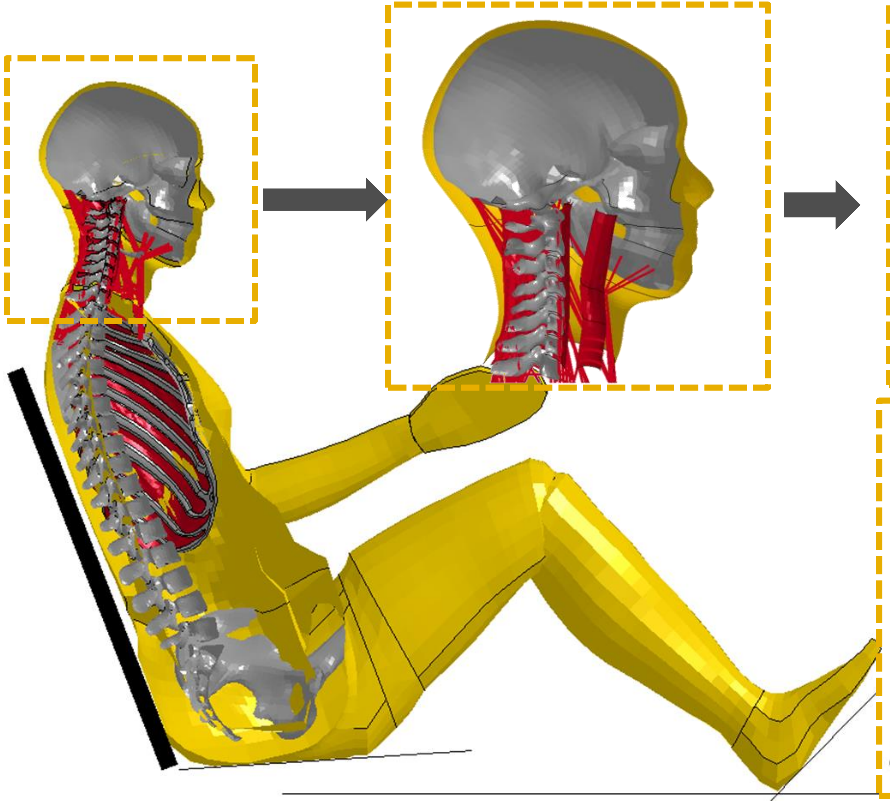
Active muscles responses must be included.

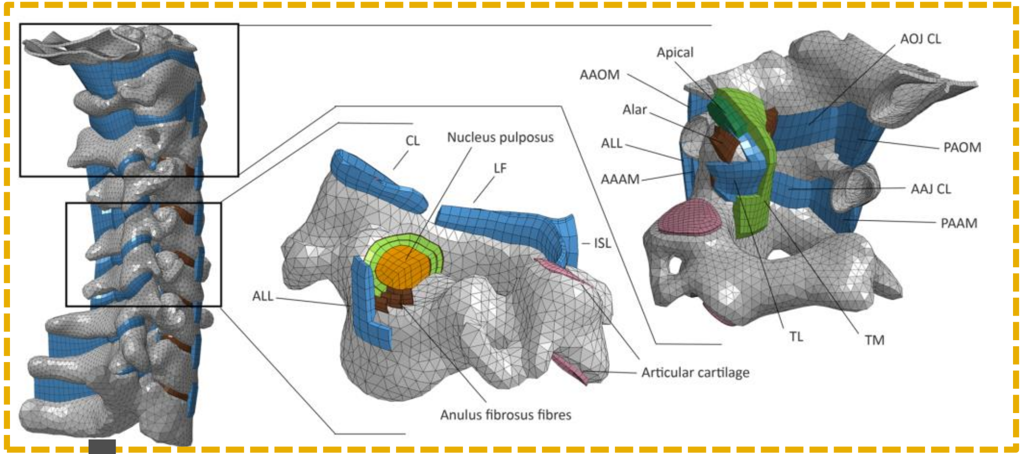


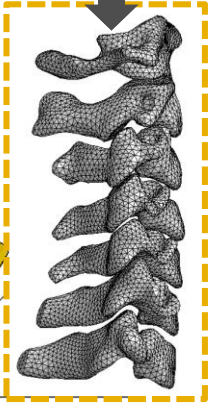
Current study focusing on **implementation and calibration of LS-DYNA PID Feedback control** of the FE models of cervical muscles

2. Method

2.1 ViVA Open HBM Head-Neck Model





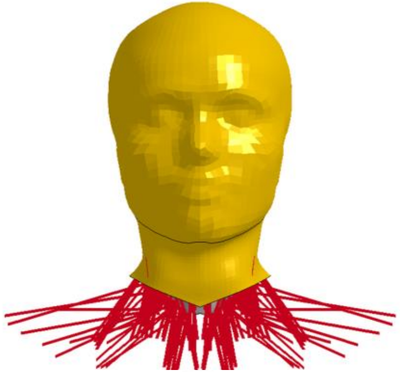


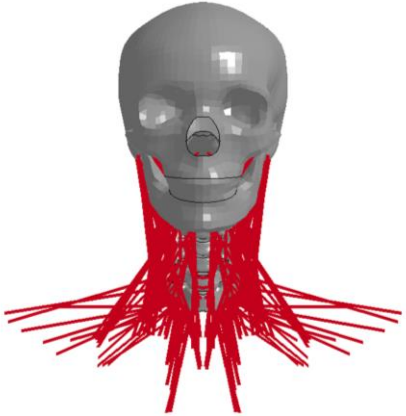
- Cervical spine model consists 116000 elements
- Head model as rigid body, mass equal to 3.58kg
- Head-neck model validated in dynamic rear impacts
- A simplified spine model also developed by removing invertebral soft tissues and replaced with kinematics compliant joints
- See Östh et al. [9,10,11]

2.1 ViVA Open HBM Head-Neck Model

No	Name of Muscles
1	M. iliocostalis cervicis
2	M. longissimus capitis
3	M. longissimus cervicis
4	M. intercostalis cervicis
5	M. interspinalis cervicis
6	M. intertransversarii anterior cervicis
7	M. intertransversarii posterior cervicis
8	M. levator scapulae
9	M. longus capitis
10	M. longus colli, craniolateral part
11	M. longus colli, medial part
12	M. multifidius cervicis
13	M. obliquus capitis inferior
14	M. obliquus capitis superior
15	M. omohyoid, venter inferior
16	M. omohyoid, venter superior
17	M. sternohyoid
18	M. sternothyroid
19	M. thyrohyoid
20	M. rectus capitis anterior
21	M. rectus capitis lateralis
22	M. rectus capitis posterior major
23	M. rectus capitis posterior minor
24	M. rhomboideus minor
25	M. scalenus anterior
26	M. scalenus medius
27	M. scalenus posterior
28	M. semispinalis capitis
29	M. semispinalis cervicis
30	M. serratus posterior superior
31	M. splenius capitis
32	M. splenius cervicis
33	M. sternocleidomastoideus
34	M. trapezius, pars descendens

34 Muscles





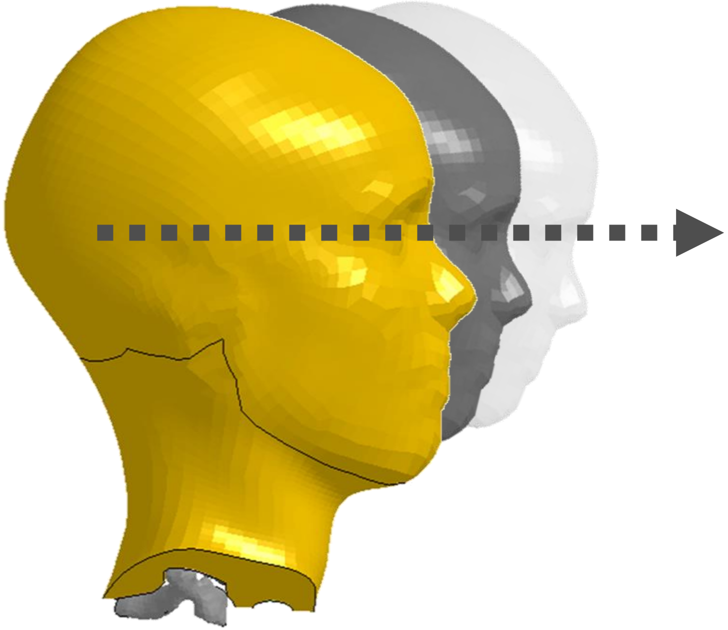
- Passive muscles model

- 129 fascicles of muscles each side

- 1 D Hill-type Muscles Element
- (*MAT_MUSCLE_156)

- Distal end of muscles constrained to move with T1

2.2 Vestibular – Vestibulocollic Reflex



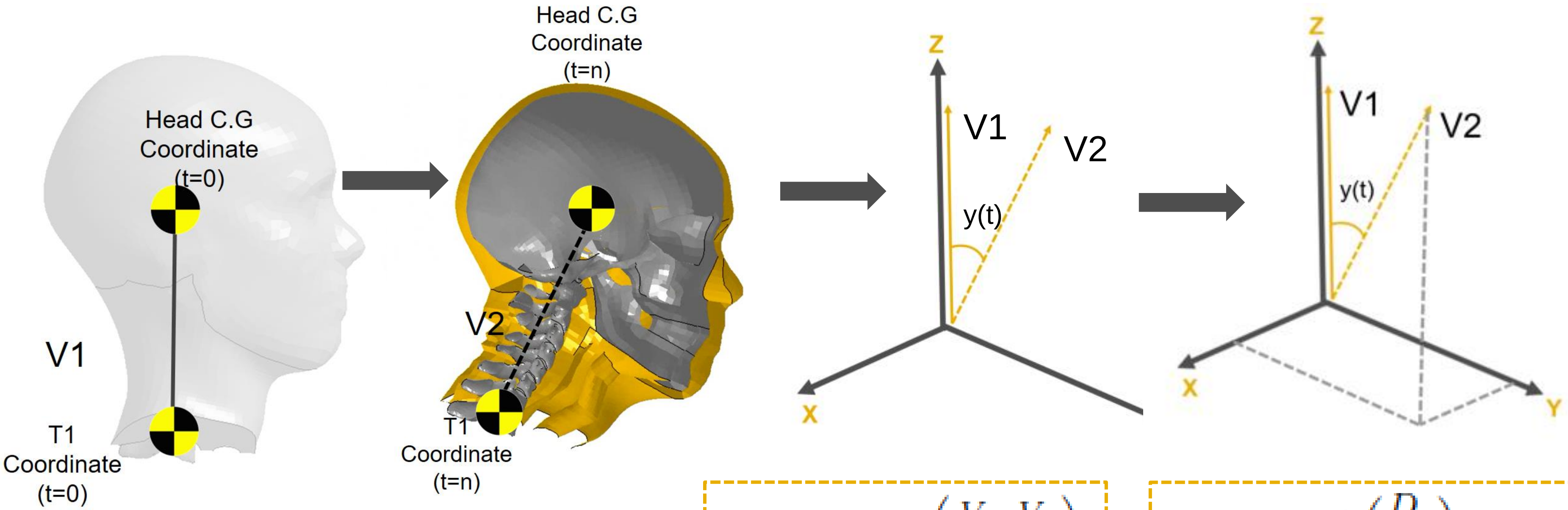
- The vestibulocollic reflex (VCR) acts on the cervical musculature to **stabilize the head in space** sensed by semicircular canal organs [12].

- The VCR reflex was **assumed to be active during rear-impact.**

- The controlling muscles activation was **adopted from Östh et al.** [13] **and Olafsdottir**. [14]

12. Goldberg & Cullen (2011)
13. Östh et al., (2012)
14. Olafsdottir., (2017)

2.3 Implementation of LS-Dyna PID Control on Cervical Muscles FE Model



$$y(t) = \cos^{-1}\left(\frac{V_1 \cdot V_2}{|V_1||V_2|}\right)$$

$$\theta(t) = \tan^{-1}\left(\frac{D_y}{D_x}\right) \cdot \pi/180$$

2.3 Implementation of LS-Dyna PID Control on Cervical Muscles FE Model

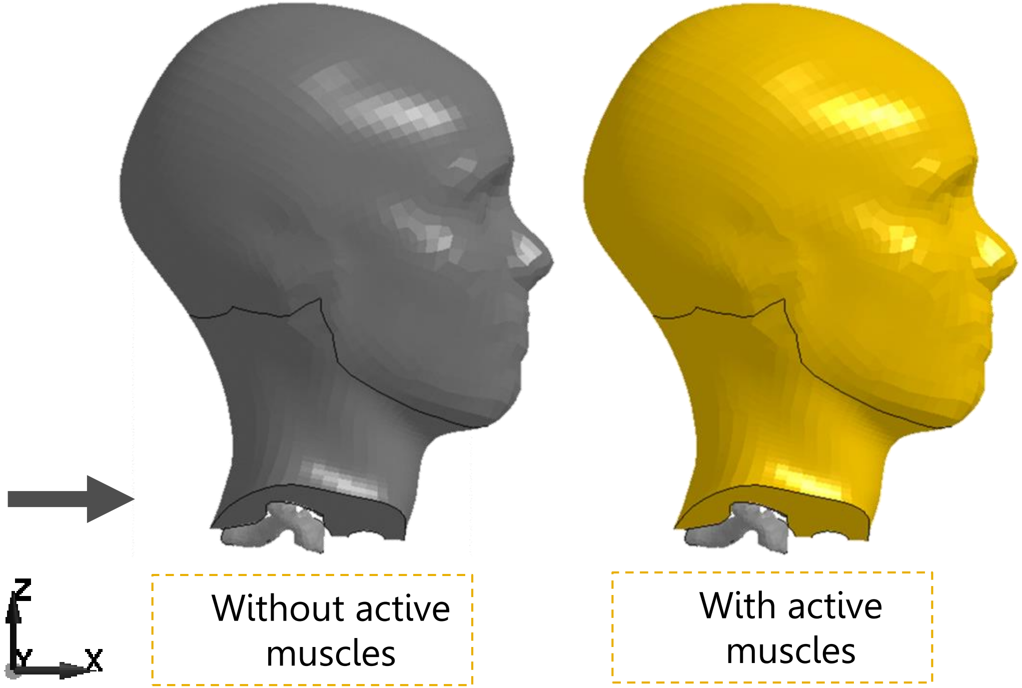
Sampling of T1 and CG at t=0 → Calculating y(t) → Delaying y(t) → Calculating θ(t) → PID Control

$$u(t) = kp \times e(t) + ki \times \int_0^t e(\tau)d\tau + kd \times \frac{de(t)}{dt}$$

→ Activation dynamics → Collecting signal → Muscles Activation Card

2.3 Implementation of LS-Dyna PID Control on Cervical Muscles FE Model

- Test case based on **Östh et al. 2017** [10]



Without active muscles

With active muscles

- Total simulation 300ms including 100 ms settling simulation with global damping
- A sine shape pulse applied in T1 vertebra
- Peak acceleration 47 m/s2
- Duration of 0.1 s (ΔV=3m/s2)

No	Parameters	Feedback Gains based on Olafsdottir 2017 [17]
1	Co-contraction level	0.05
2	Proportional gain (kP)	1.301
3	Integral gain (kI)	0.000
4	Derivative gain (kD)	470
5	Delay response time	20 ms

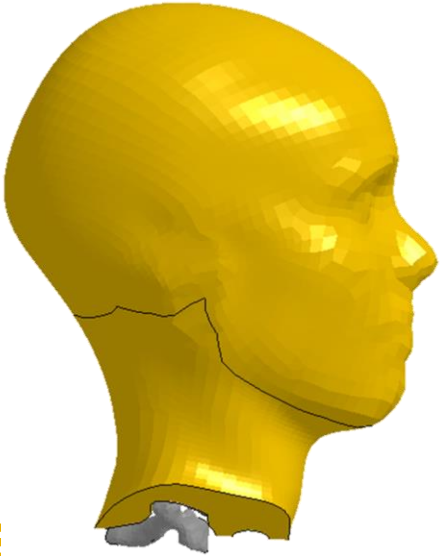
2.4 Calibration of LS-Dyna PID Control Feedback Gains

- Experimental data based on **Ono et al. 2006 & Sato et al. 2014 [15,16]**

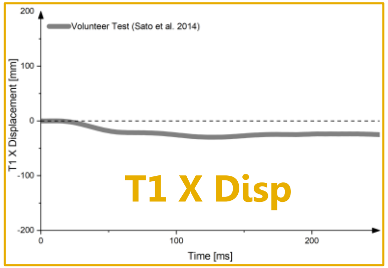
Goal of Calibration:

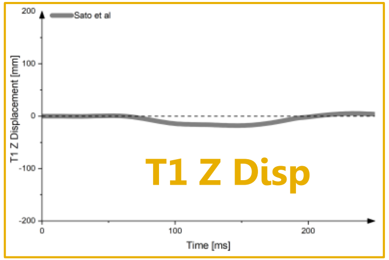
- Head C.G kinematics of the **model match the head C.G kinematics of the published volunteer data**

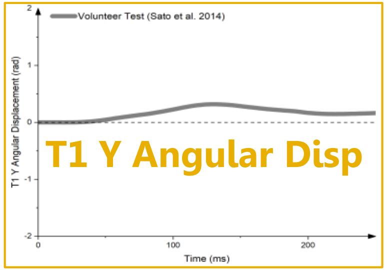
- Total simulation 350ms including 100 ms settling simulation with global damping
- T1 motions from the published volunteer data were prescribed in the T1 of the model



Prescribed in T1 of the Model

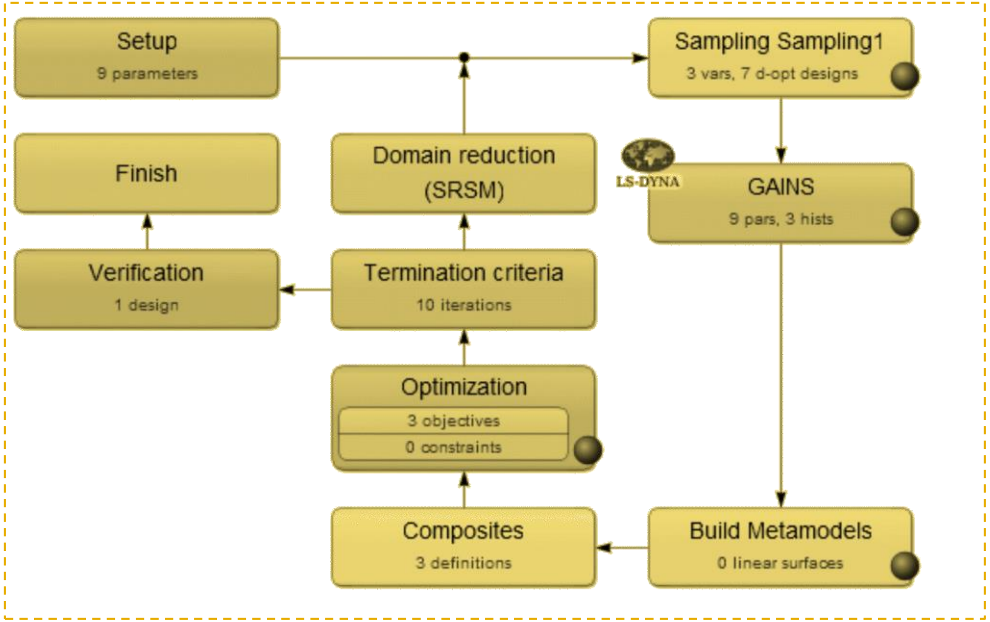






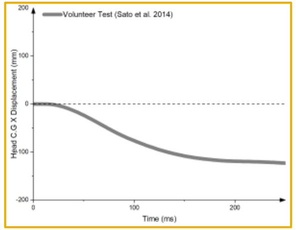
15. Ono et al., (2006)
16. Sato et al., (2014)

2.4 Calibration of LS-Dyna PID Control Feedback Gains

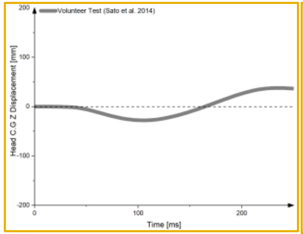


No	Parameter	Ranges	LS-OPT
1	Proportional gain (kP)	0.01 – 5.00	Add as * (star) parameter
2	Derivative gain (kD)	1- 1000	Add as * (star) parameter
3	Delay response time	15ms - 88ms	Add as * (star) parameter

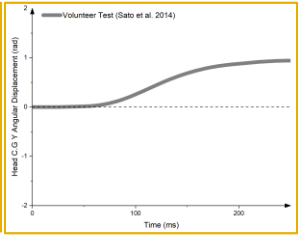
Head C.G X Disp



Head C.G Z Disp



Head C.G Y Ang Disp



Composites

Composite definition

Z_Head
Curve Matching: Measure 'Head_Z' against target 'HeadZ_FSK' using MSE of ordinate values

X_Head
Curve Matching: Measure 'Head_X' against target 'HeadX_FSK' using MSE of ordinate values

AngY_Head
Curve Matching: Measure 'Head_Y' against target 'HEADY_FSK' using MSE of ordinate values

3. Result & Discussion

3.1 Test Case Comparison

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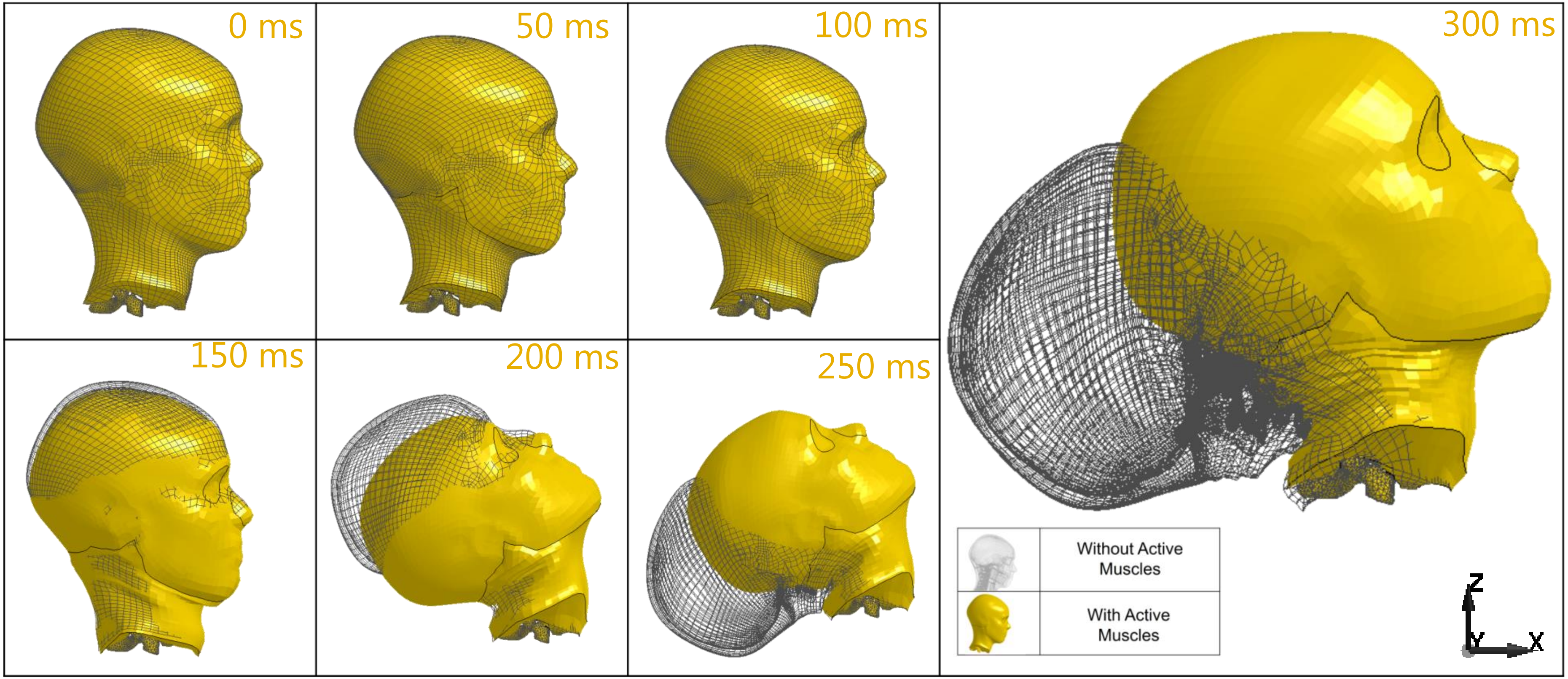
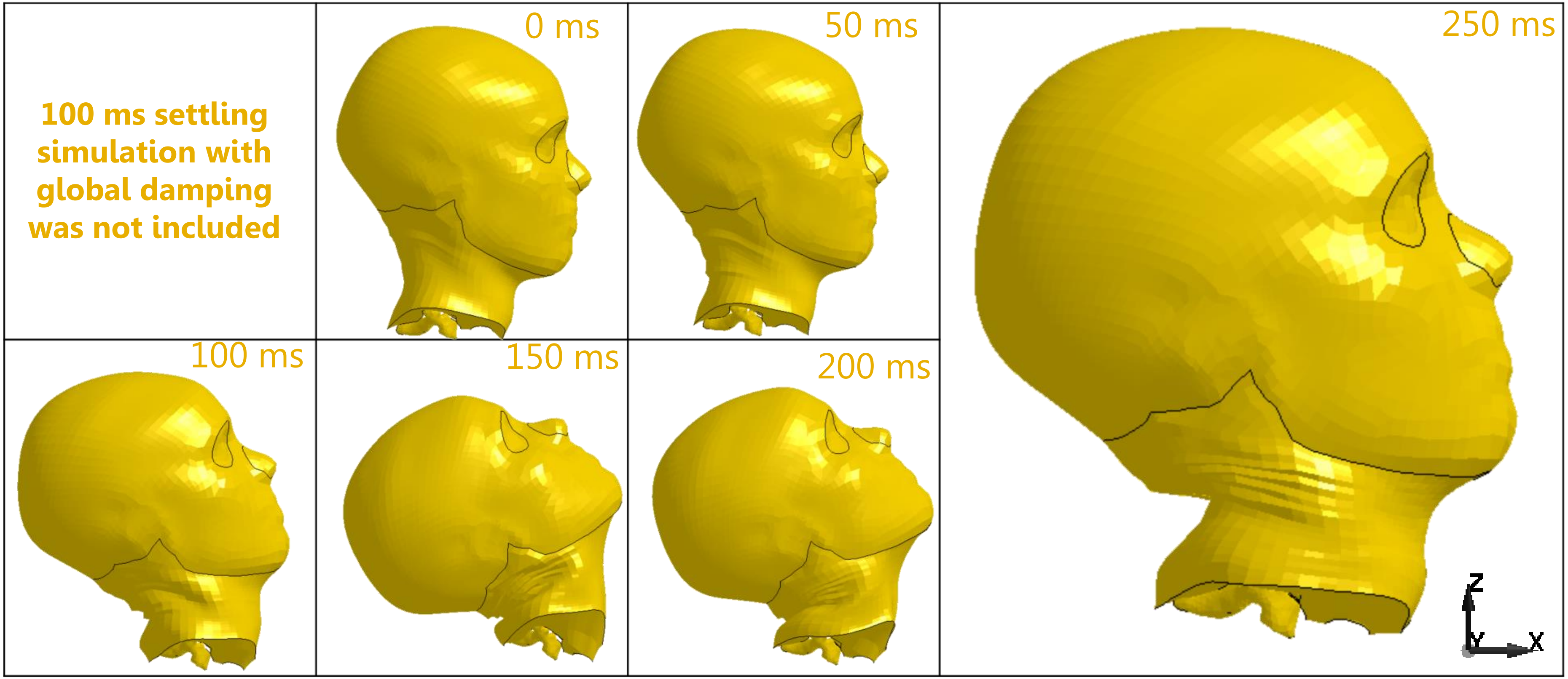


3.2 Result of Calibration

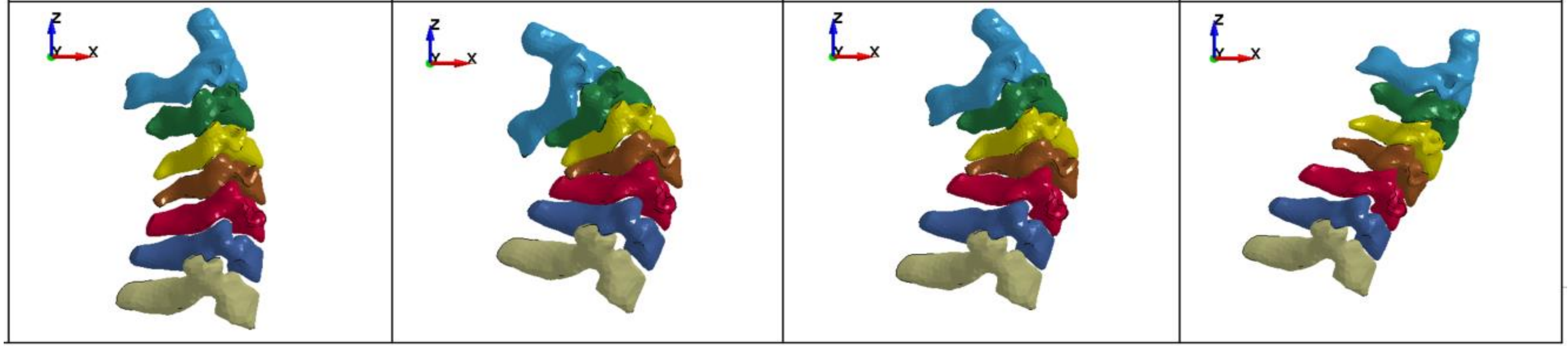
No	Parameter	Gains
1	Proportional gain (kP)	**1.96**
2	Derivative gain (kD)	**557.58**
3	Delay response time	**38.26ms**

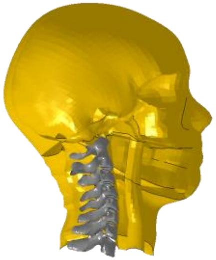
3.2 Result of Calibration

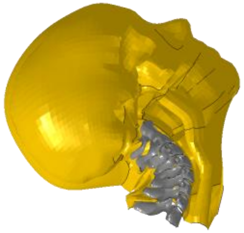


3.2 Calibration Results

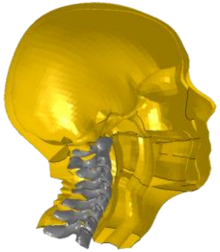
Retraction	Extension	Extension	Flexion
60ms	140ms	220ms	300ms



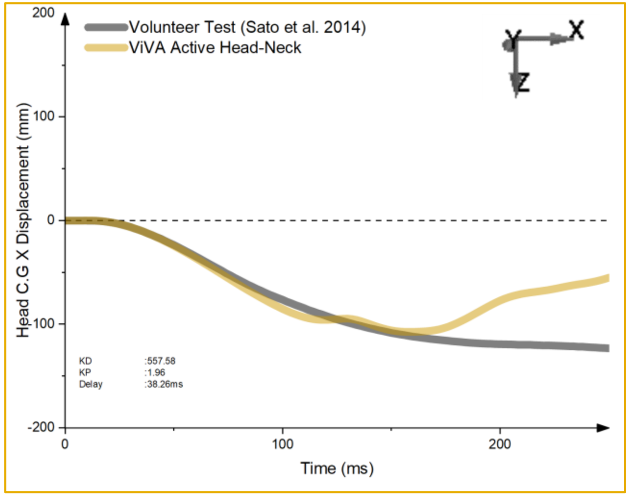


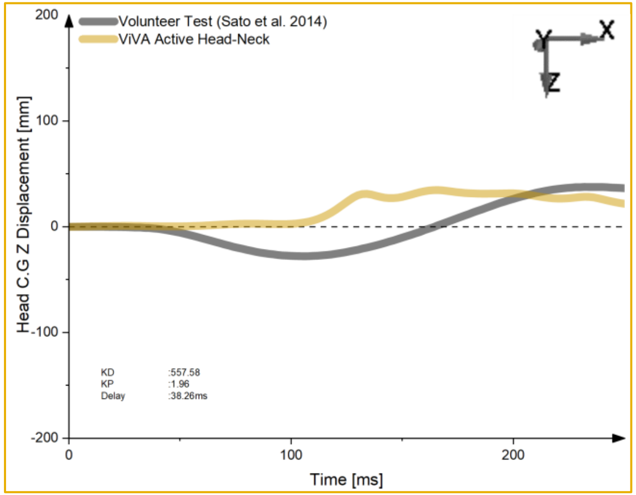


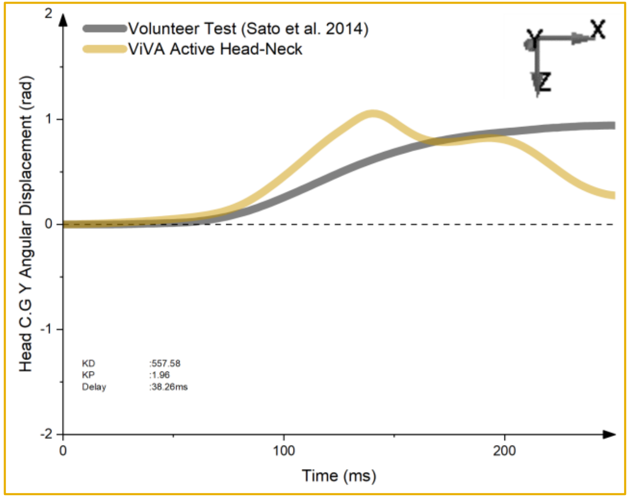
Long duration of extension in the model



3.2 Calibration Results







Head C.G Displacement in X Direction

Head C.G Displacement in Z Direction

Head C.G Angular Displacement in Y Direction

4. Conclusion

4. Conclusion

- The LS-Dyna PID (Proportional Integral Derivative) feedback controls were successfully implemented on the Finite Element (FE) models of cervical muscles of ViVA OpenHBM Head-Neck model.

- Based on the test case simulation, the cervical muscles with active reflexive feedback control showed to influence the head kinematics of the model.

- The PID control gains were successfully calibrated by conducting a parameter identification using LS-OPT.

- The head C.G motion of ViVA OpenHBM Head-Neck model with active active reflexive feedback control showed good agreement in horizontal direction while further improvements are needed to match the volunteer head C.G motion in the vertical and angular direction.

5. Acknowledgement & Reference

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- All pictures that used in this presentation were downloaded from open sources/public domain/ Chalmers-owned copyright.

- **Download ViVA Model at: http://www.chalmers.se/en/projects/Pages/OpenHBM.aspx.**

5. Acknowledgement & Reference

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